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OPTICAL SIGNAL PROCESSING USING NON-LINEAR OPTICS(U)  
UNIVERSITY OF SOUTHERN CALIFORNIA LOS ANGELES

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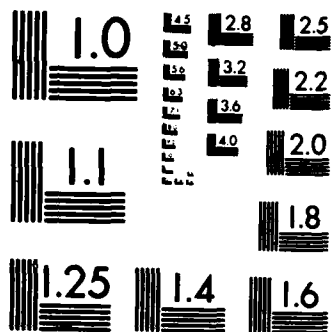
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<p>The 2-D correlation/convolution which can be achieved in real time via four wave mixing in nonlinear materials has been investigated in detail to determine the accuracy and signal power investigated in detail to determine the accuracy and signal power possible. This analysis was initiated under other support; the experimental confirmation was completed under this contract. The analysis which is based on Fourier transforms of the equations of non-linear interaction has resulted in a closed form solution for the output and clearly shows how it differs from the desired 2-D correlation. In the example of a scene that is searched for given objects, the accuracy decreases as the ratio of scene to object size increases. The accuracy also resulting in a trade-off between accuracy, size of scanned scene, and power or signal to noise ratio in the output. The analysis was confirmed experimentally in a colinear four wave interaction in the photorefractive material bismuth silicon oxide at 5145 A. The accuracy of the correlation between relatively simple patterns was measured and agreed reasonably well with the prediction of the analysis.</p>					
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**OPTICAL SIGNAL PROCESSING USING NON-LINEAR OPTICS  
RESEARCH PROGRESS AND FORECAST REPORT**

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# Optical Signal Processing Using Non-linear Optics Research Progress and Forecast Report

Grant AFOSR-84-0207

William H. Steier

## Introduction

This report summarizes the results obtained on Grant AFOSR-84-0207, "Optical Signal Processing Using Non-linear Optics", for the period 8/1/84 through 11/30/85. The proposed directions for the research during the next 12 months are also outlined.

## 2-D Correlations/Convolutions Via Four Wave Mixing

The 2-D correlation/convolution which can be achieved in real time via four wave mixing in non-linear materials has been investigated in detail to determine the accuracy and signal power possible. This analysis was initiated under other support; the experimental confirmation was completed under this contract. The analysis which is based on Fourier transforms of the equations of nonlinear interactions has resulted in a closed form solution for the output and clearly shows how it differs from the desired 2-D correlation. In the example of a scene that is searched for given objects, the accuracy decreases as the ratio of scene to object size increases. The accuracy also decreases as the length of the nonlinear material increases resulting in a trade-off between accuracy, size of scanned scene, and power or signal to noise ratio in the output.

The first result of this analysis is the realization that a non-colinear interaction is considerably less accurate than the colinear. In the typical four wave mixing scheme, the two inputs  $B_1$  and  $B_2$  propagate at a small angle to each other within a non-linear medium; the pump wave is counter to one of the inputs. This angle between the beams



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results in a lateral translation between the patterns as they propagate through the non-linear material. The result is a correlation between smoothed versions of the inputs and a considerable error.

A colinear interaction is possible so long as the two inputs are distinguishable via either polarization or wavelength. A typical polarization scheme is shown in Figure 1. Input 2 interacts with the plane wave pump 3 to write a grating in the non-linear material. Input 1 reads the grating and results in the scattered output 4. Note that a true  $X_3$  material such as  $CS_2$  will not work in all cases since the output will contain the correlation and its complex conjugate. If the inputs are real, this is not objectionable.

The result for the colinear cases is:

$$B_4(x,y) = K_c \int_{-\infty}^{+\infty} dx' dy' B_1(x',y') B_2(x'+x, y'+y) \frac{1 - \exp(i\gamma_c z_o)}{-i\gamma_c z_o}$$

where

$$\gamma_c = i\alpha \frac{k_0}{nF^2} (xx' + yy')$$

$K_c$  = constant containing the nonlinear coefficient  $X_3$

$z_o$  = thickness of non-linear material

$\alpha$  = linear loss coefficient

$F$  = Focal length of the F.T. lens.

The above expression differs from the desired 2-D correlation by the last bracketed term containing the exponent. The origin of this term is the k vector mismatch. Near the origin the correlation is relatively accurate, but the accuracy decreases as the size of the two input patterns increase. This is important in a typical case where a scene is scanned for a particular object. For large fields of scan, the accuracy decreases, and the possibility of false alarms increases.

This analysis has been confirmed by an experiment which was performed under the support of this grant. In the experiment, input 1 is a square aperture of side "a" located

on the axis. Input 2 is similar square aperture but located  $X_0$  off axis. We are, therefore, searching over range  $2X_0$  by  $2X_0$  for the square aperture of side "a". In the experiment, the relative correlation power (RCP) was measured and compared to the calculated value. The RCP is the ratio of the total integrated power in the correlation peak, relative to the power in the perfect correlation and is, therefore, the relative detected power for a threshold detection scheme.

The experimental layout is shown in Figure 2. C is the photorefractive material bismuth silicon oxide which is oriented so that the beams propagated along the 001 direction. The half wave plate  $H_1$  rotates the polarization of the write beam  $B_2(x,y)$  to be perpendicular to that of the read beam  $B_1(x,y)$ . The mask I contains an on-axis rectangular aperture which is illuminated by  $B_1$  and three off-axis rectangular apertures illuminated by  $B_2$ . Three correlations are thus recorded simultaneously for accuracy. The slit on the chopper (Ch) wheel selected one of the correlations at a time for measurement by the PMT.

Typical comparison of the experimental data (crosses and dashed line) and the calculated data is shown in figure 3. The parameters c, d, and b are defined on the figures and earlier in this report. The results closely follow the predicted curve and confirm the analysis.

#### Two Dimensional Modulator/Switch Using the Photorefractive Etalon

A study has been initiated of an optical etalon filled with a photorefractive material. The transmission of the etalon at the read wavelength ( $\lambda_R$ ) can be controlled by the intensity of the control beam at wavelength  $\lambda_C$ . Two dimensional arrays of these devices have numerous applications in optical signal processing, optical computing, and optical interconnect networks. The preliminary analysis predicts switching times of  $\sim 100$  ns and switching energies of  $\sim 100$  pJ. While these numbers are about one order of magnitude

larger than those for the GaAs-GaAlAs excitation nonlinearity, the photorefractive devices have some definite advantages and appear to have several potential applications. In particular, the photorefractive effects is wideband while the excitation effect is very narrow band.

The analysis for BSO is complicated by the optical activity of the medium which causes the normal modes to be elliptically polarized. The change in the etalon resonant frequency,  $\Delta f$ , due to the change in index  $\Delta n$ , caused by the photorefractive effect is given by:

$$\frac{\Delta f}{f_o} = \left( \frac{\Delta n}{n_o} \right)^2 + \left( \frac{\rho \lambda_o}{2\pi} \right)^2 \quad 1/2$$

Where

$f_o$  = resonant frequency of the etalon

$n_o$  = index of refraction

$\rho$  = optical rotary power of BSO =  $10^\circ/\text{mm}$  at  $\lambda_R = 8500\text{\AA}$

$\lambda_o$  = resonant wavelength.

In a particular example in which the "on" transmission of the etalon was set at 75% and "off" transmission was set at 7.5%, the following table summarizes the design.

$l$  = etalon thickness = 3mm

$R$  = mirror reflectivity at  $\omega_R = 90\%$

$E_o$  = d.c. electric field = 10kV/cm

$F$  = etalon finesse = 26

$\Delta n$  = required index change due to photorefraction =  $25 \times 10^{-6}$ .

The predicted switching time is 400 nsec, and the predicted switching energy is 2.4 nJ. The cross-sectional area of the switch is  $6.3 \times 10^{-6} \text{cm}^2$ . The optical rotary effect in BSO seriously effects the performance of the switch. Without this effect the switching time and the switching energy would both be reduced by a factor of four.

The semi-insulating semiconductors (InP:Fe, GaAs:Cr) are very promising photorefractive materials. They are also expected to be as sensitive as BSO, to have high speed because of their high mobility, and to be usable in the near IR where semi-



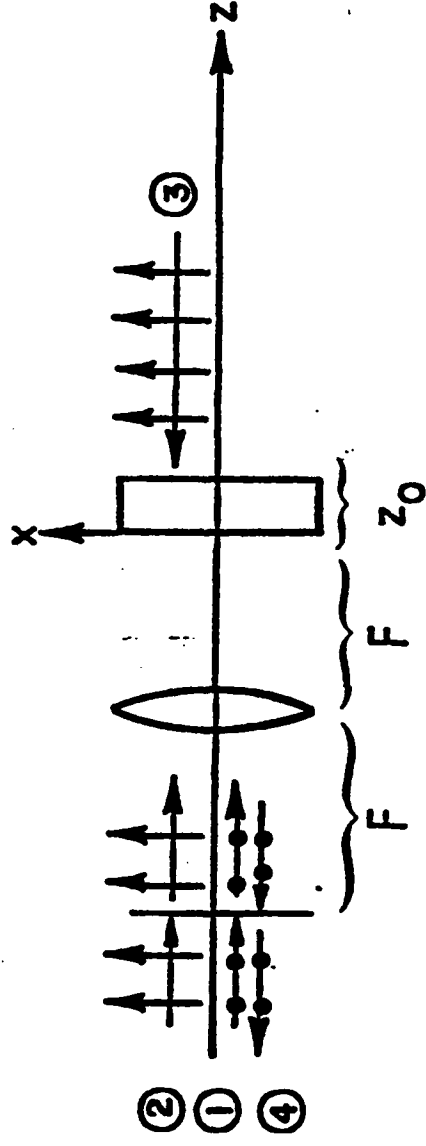
conductor lasers are available. At present, the data available on these materials is not complete. Measurements of the material properties are underway in our laboratory under separate support.

Based on some recent results, the etalon switch using InP:Fe would have less than one microsecond switching speed and  $\sim 200$  pJ switching energy. The control wavelength is  $1.06\mu$ , the read wavelength is  $1.32\mu$ .

A more detailed analysis of the etalon switch is being developed which includes the transverse spatial properties. The analysis predicts the transverse pattern of the output beam for a given control beam pattern and hence gives a more accurate picture of the beam switching.

An experiment is currently being designed to observe the switching phenomena. The experiment includes an oven to stabilize the etalon temperature, a tunable laser for the read beam, and an ion or a Nd-YAG laser for the control and erase beam.

- Collinear, degenerate FWM using orthogonal polarizations:



- ② and ③ write a grating, ① reads it
- Can't use a true  $\chi^{(3)}$  material (e.g.,  $\text{CS}_2$ )
- Strong noise at the input/output plane

FIGURE 1

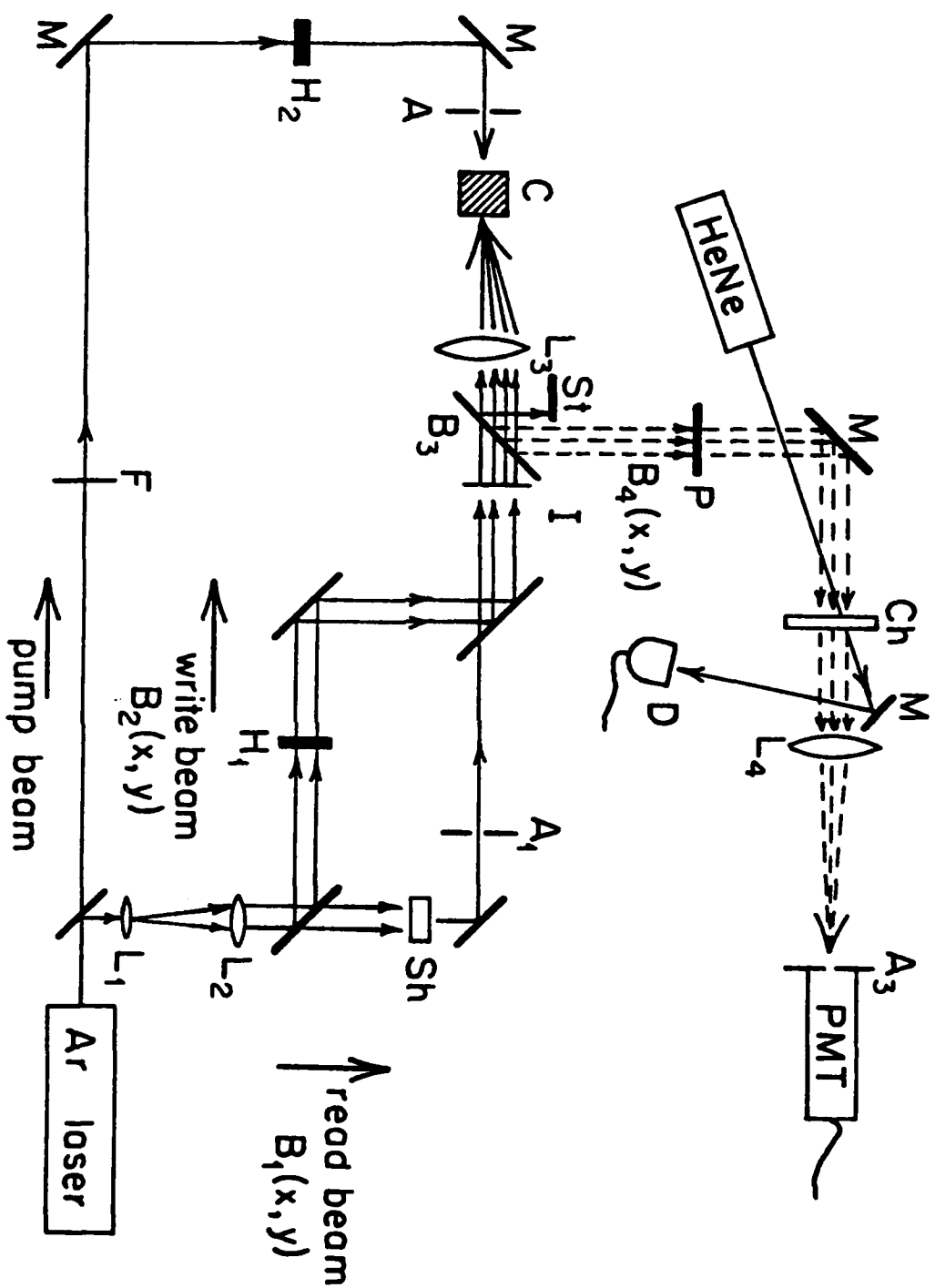
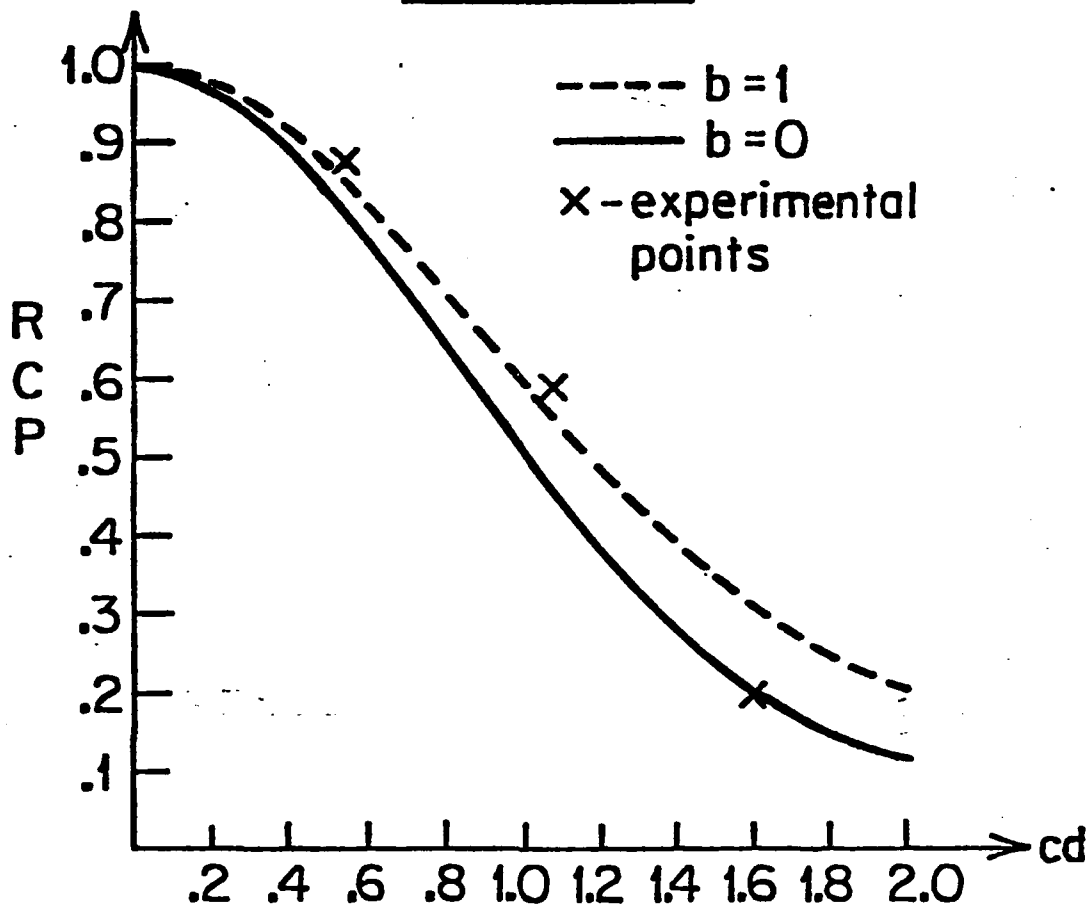


FIGURE 2

# RCP vs cd



$$\left( c = \frac{z_0 a^2}{h \lambda F^2}; \quad d = \frac{x_0}{a}; \quad b = \alpha z_0 \right)$$

$$cd = \frac{z_0 a x_0}{h \lambda F^2}$$

FIGURE 3

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